Factors Affecting the Backscattering Probability in the Sea

William M. Balch
Bigelow Laboratory for Ocean Sciences
POB 475
McKown Point
W. Boothbay Harbor, ME 04575
phone (207) 633-9600 fax (207) 633-9641 email bbalch@bigelow.org
Award Number: N000149810882
http://www.bigelow.org

LONG-TERM GOALS

The long-range goal of my ONR-sponsored research has been to use bio-optical techniques to understand the distributions, in space and time, of phytoplankton and associated particles (such as detritus, coccoliths, viruses, etc.). In particular, my work has focused on understanding the scattering properties of different types of marine particulate material, in order to better model radiative transfer in the sea.

OBJECTIVES

The objectives of this work are to describe the variance in backscattering probability ($\tilde{b}_b$) in coastal waters and to partition its variability according to cell size, taxa, and degree of eutrophy.

APPROACH

Our approach has been to make underway measurements of the inherent optical properties, absorption, attenuation (and by difference, scattering), plus the volume scattering function (from which backscattering is calculated). We also collect samples for chlorophyll, particulate organic carbon and nitrogen, particulate inorganic carbon (calcite), and cell counts. Due to the importance of backscattering probability to the surface remote sensing reflectance, we are focusing on surface measurements, covering as wide a diversity of environments as possible. Personel involved in this work are myself, David Drapeau, Bruce Bowler, Amanda Ashe, Dr. Robert Vaillancourt (post-doc) and Dr. Joaquim Goes (post-doc), all from Bigelow Laboratory.

Detailed Methods

Flow-Through System

Our flow-through system is equipped with several sensors, with data integration and logging performed by National Instruments LabVIeW software run on two pentium processor computers. The system receives time and the ship's geographic position continually from a Garmin 220 global positioning system, the antenna of which is mounted outside of the ship, off the stern. Seawater first enters a vortex debubbler (SUNY UDB1), then into a 4 foot tall de-bubbler, equipped with a 1 mm screen to keep the largest zooplankton and salps out of the optical instrumentation, then the flow enters an InterOcean thermal conductivity sensor. It measures salinity with an accuracy of +0.05 Practical

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**
4. TITLE AND SUBTITLE **Factors Affecting the Backscattering Probability in the Sea**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Bigelow Laboratory for Ocean Sciences,180 McKown Point Road,West Boothbay Harbor,ME,04575**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Salinity Units and temperature to an accuracy of +0.1°C. Following the temperature/salinity measurements, the flow bifurcates into a Turner 10au fluorometer for monitoring underway fluorescence and a tertiary debubbler prior to measurments of light scattering. The fluorometer is equipped with a daylight white F4T5D lamp, blue-violet excitation filter (peak excitation 438nm with half band pass of 380-500nm) and red emission filter (high pass interference filter passing all wavelengths >665nm. Due to fast growing bio-fouling organisms in the Gulf of Maine, the fluorometer is cleaned regularly.

For the light scattering measurements, water passes from the tertiary debubbler, via peristaltic pump, into a Wyatt Technologies Model Dawn laser light scattering photometer at a flow-rate of ~9ml min-1. The photometer operates with an 10 mW Argon ion laser (514 nm) which is directed into the center of a flow-through cuvette, whereupon, seawater is viewed by 15 photodiodes arranged between 21.54° and 158.14°. Included in the 18 detectors are two photodiodes for laser power monitoring (one prior to passage through the viewing cuvette, and one post). The laser beam has a 1/e2 gaussian beam profile radius of 0.39 mm which makes the effective viewing volume of the light-scattering photometer 0.25 ml. All detectors are scanned at rates up to 400 HZ. In fact, for most flow-through applications, we slow the scanning rate to 200 HZ in order to not sample the same seawater volume twice. The volume scattering data were fit to the Beardsley-Zaneveld function (Beardsley and Zaneveld, 1969), which was then integrated in the backwards direction in order to calculate total backscattering. Absolute calibration of the instrument was achieved by pushing 0.2µm filtered, analytical grade, methanol through the optical cell, correcting for differences in the index of refraction between water and methanol. To correct for any bio-fouling or instrument drift, vicarious calibrations were run throughout the cruise in which 0.2µm filtered Milli-Q distilled water was pushed through the flow cell.

The LabView software, which controls the Wyatt light scattering photometer, can be programmed to calculate averages and standard deviations of seawater volume scattering data to any desired time period. For field applications, we typically average the data for about 50 s (which then represents an effective volume viewed of ~9ml). The statistics are highly informative for understanding the variance of the optics due to different particle types. Because of the potentially high backscattering probability of calcite, we also measure seawater pH to verify that the pH is sufficiently high to prevent calcite dissolution. Following the first 50s of measurements on raw seawater, another peristaltic pump is activated by the LabView control system, which injects 0.5% glacial acetic acid into the flow stream, and mixes it by running it through a Teflon mixing column. This drops the pH to about 5.8 to dissolve any calcium carbonate. Once the pH stabilizes at the more acidic value, volume scattering is re-sampled, and average backscattering re-calculated. The difference between the raw and acidified backscattering values represents the "acid-labile" backscattering. Using field measurements, we have calibrated this acid-labile backscattering to atomic absorption estimates of suspended calcite concentration (r2=0.83). The time for a complete acidification cycle can be adjusted, but we have preferred to collect average backscattering values such that one complete raw/acidification cycle takes 4 minutes. This means that during any passage, we would be logging a data point about once every 2000 meters.

Water next flows into an AC-9 (Wet Labs, Oregon). This instrument simultaneously measures spectral beam attenuation and spectral absorption at nine wavelengths using a dual path optical scheme. Fundamentally, this consists of two pressure housings, with the absorption and attenuation beam

paths. The absorption light path passes through a reflective tube while the the attenuation light path passes through a non-reflective tube. A rotating filter wheel provides the 9 different wavelengths, between 412-715 nm. The accuracy of the attenuation and absorption measurements are +0.005m-1 with linearity error of +0.1%. With access to attenuation (c) and absorption (a) information, we calculate total scattering, b (= c - a).

The last in-flow measurement is with the Hobie Labs Hydroscat-2. This instrument is set to view an enclosed, 20 liter, sand-blasted, stainless steel containor (painted flat black within). This vessel has a cleaning brush inside to remove bubbles from the viewing window. The instrument measures volume scattering at 142^{o}, and extrapolates to backscattering using an assumed volume scattering function. It makes measurements at 470 and 676nm plus it also measures chlorophyll fluorescence.

Water-leaving radiance and downwelling irradiance (for calculating remote sensing reflectance) is measured from the ship using a Satlantic SeaWiFS Aircraft Simulator (SAS). This consists of a radiance sensor mounted on the bow, and an irradiance sensor mounted on top of the ship, as far from any potentially shading structures as possible. The radiance detector views the water forward of any shipwake, at ~30^{o} from nadir, depending on sea state and glint conditions. The distance of the sensor to the water is ~30m. The direction of the sensor is changed periodically, as the sun's position changed, so, when possible, the sensor is viewing the water 90^{o} from the sun's azimuth, free from any sun glint. Protocols for operation and plaque calibration were made according to SeaWiFS technical memorandum #25 and the NASA SeaWiFS SEABOAR Experiment. Data in real time are filtered for sun glint and sea foam by eliminating the top 95% of the data. Between the hours of 1000 and 1400, all data are logged at 10Hz. Outside of this time, averages of the glint and foam-filtered data are logged every 16 seconds.

Discrete Samples:

Every hour a water sample was taken for suspended $CaCO_3$, particulate organic carbon, chlorophyll, and microscope counts. The technique of Fernandez et al. ((Fernández et al. 1993)) was used to measure $CaCO_3$ concentrations. Briefly, 500 ml samples are filtered onto 0.4µm pore-size polycarbonate filters, and rinsing first with filtered sea water, then borate buffer (pH=8) to remove seawater calcium chloride. Filters are placed in trace metal free centrifuge tubes with 5 ml 0.5% Optima grade Nitric acid. Next, the Ca concentration is measured using atomic absorption spectrometry. Chlorophyll and particulate organic carbon are measured according to the JGOFS protocols ((JGOFS 1996)).

A 60ml water sample was taken for coccolithophore and coccolith counts. Brown glass bottles are rinsed 3X with each sample prior to final filling. Samples are preserved with 4% buffered formalin and, after the cruise, settled in 10 ml counting chambers prior to counting detached coccoliths and plated coccolithophores ((Utermöhl 1931; Utermöhl 1958). Microscope enumeration of detached coccoliths and plated coccolithophores is made using an Olympus BH2 microscope with polarization optics which allows quantification of birefringent $CaCO_3$ coccoliths, and coccospheres. For statistical reasons, 200 coccoliths or cells are counted from each sample, when available.

Data manipulation

The data output from our flow-through system is: time, latitude, longitude, downwelling PAR (uEin m^{-2} s^{-1}), fluorescence (volts; and calibrated with discrete extractions), backscattering (m^{-1}), acid-labile backscattering(m^{-1}) , absorption (m^{-1}), and attenuation (m-1). Standard error is also recorded for each optical parameter. Derived products from this data set are: suspended calcite (gC as calcite m^{-3}), chlorophyll specific absorption (a*; m^2 mg chl^{-1}), $\tilde{b}_b$ (=bb/b; important for remote sensing models), particle b_b(l), predicted remote sensing reflectance at each of the visible wavelengths measured by the AC-9, using Gordon et al.'s (1988) equation:

$$R/Q= \sum_{i=1}^{2} l_i \, (bb/(a+bb))^i$$

where Q is the variable distribution function (often set equal to p), and l_1 = 0.0949 and l_2 = 0.0794.

WORK COMPLETED

We sailed aboard the R/V Linke, in June and July of 1999, with ~3000 miles of coverage in the Gulf of Maine. Our original cruise in the Gulf of Mexico (slated to run in February, 1999, between Tampa, FL and Progresso, Mexico) was inadvertantly cancelled due to ship problems, which forced us to move operations into other waters. Fortunately, we were offered space aboard the R/V Linke, which provided us ideal coverage in water of much higher turbidity than we could have achieved on the original cruise track in the Gulf of Mexico. The R/V Linke cruise started well up the Penobscot River (mid-coast Maine), and went into the most stratified part of the Wilkinson Basin (central Gulf of Maine). It also covered the region between Portland and Yarmouth for comparison to other data sets that we have collected as part of a NASA project. Shiptime on the Linke was supplied by NSF.

RESULTS

It has been 3 months since the cruise ended, and samples are still being processed. Backscattering measured by two independent instruments (Wyatt Technologies Dawn Laser Light-Scattering Photometer and the Hobie Labs Hydroscat 2) showed reasonable agreement, with some notable differences as the shape of the volume scattering function changed (which is tracked by the Wyatt instrument but not by the Hobie Labs Instrument; Fig. 1). The Hobie Labs instrument allowed accurate measurements of the wavelength dependence of backscattering (which is how we converted the Wyatt measurements at 512nm to 470nm, for comparison of the two instruments in Fig. 1). It is clear that variability in $\tilde{b}_b$ was well related to the transition from Case I to Case II waters, with values of <1% in riverine waters and values >2% offshore. The wavelength dependence of backscattering also changed significantly from riverine to marine waters (Fig. 2). The combined effect of wavelength dependence of bb and b made for backscattering probabilities which had little wavelength dependence in the rivers, and highly wavelength dependent offshore. The shape of the volume scattering function occasionally changed significantly over this river/marine transition, which caused divergence in bb estimates by the two instruments (since the Hobie Labs instrument only measures one angle of the volume scattering function). Nevertheless, results from the two light scattering photometers were usually in good agreement. When the cell counts are completed, we will address the impact of taxonomy on $\tilde{b}_b$. It is also worthy of note, that we have the ability to relate variability in $\tilde{b}_b$ to variations in remote

sensing reflectance based on our above-water radiance measurements. These analyses are being completed now.

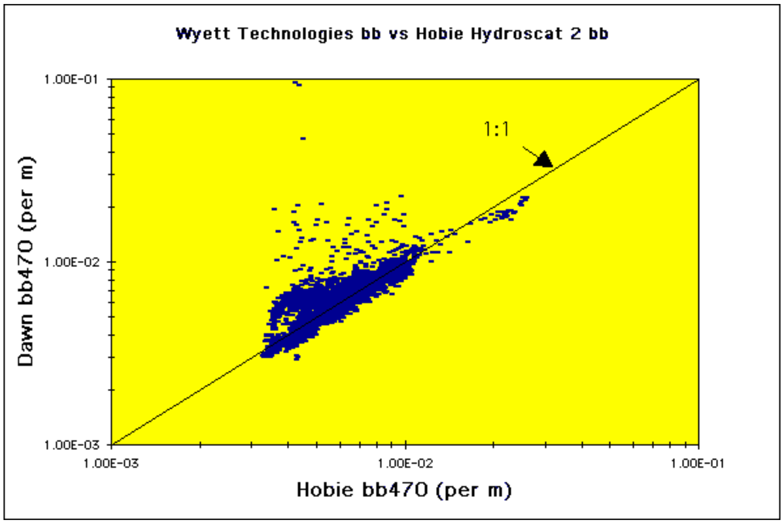

Fig. 1- Backscattering measured by two instruments, the Wyatt Technologies Dawn Laser Light-Scattering Photometer and the Hobie Labs Hydroscat 2 using Gulf of Maine seawater samples. See text for details on the measurements.

IMPACT/APPLICATIONS

This continuous underway data set for $\tilde{b}_b$ represents one of the largest of its kind, including Case I and Case II waters (particle and/or DOC dominated). Preliminary analyses show that widely used models for $\tilde{b}_b$ (b_b/b) are extremely limited in their accuracy when applied to field situations and these data set will go far towards production of new relationships for prediction of $\tilde{b}_b$. Besides absorption, particle backscattering is the other inherent optical property which determines remotely-sensed reflectance (Gordon et al. 1988); factors that affect backscattering by marine particulate material are poorly understood (especially given that we can only account for ~10% of its variability!). Thus, our simultaneous measurement of a, b, c, b_b, plus bio-optical variables, is a unique data set which can be used to investigate factors affecting the variability of $\tilde{b}_b$ and improve its prediction in the field. A new algorithm for predicting $\tilde{b}_b$ is the major application of this work.

TRANSITIONS

These data are being used by ourselves, as well as the SeaWiFS project to better understand factors that cause $\tilde{b}_b$, and remote sensing reflectance to vary.

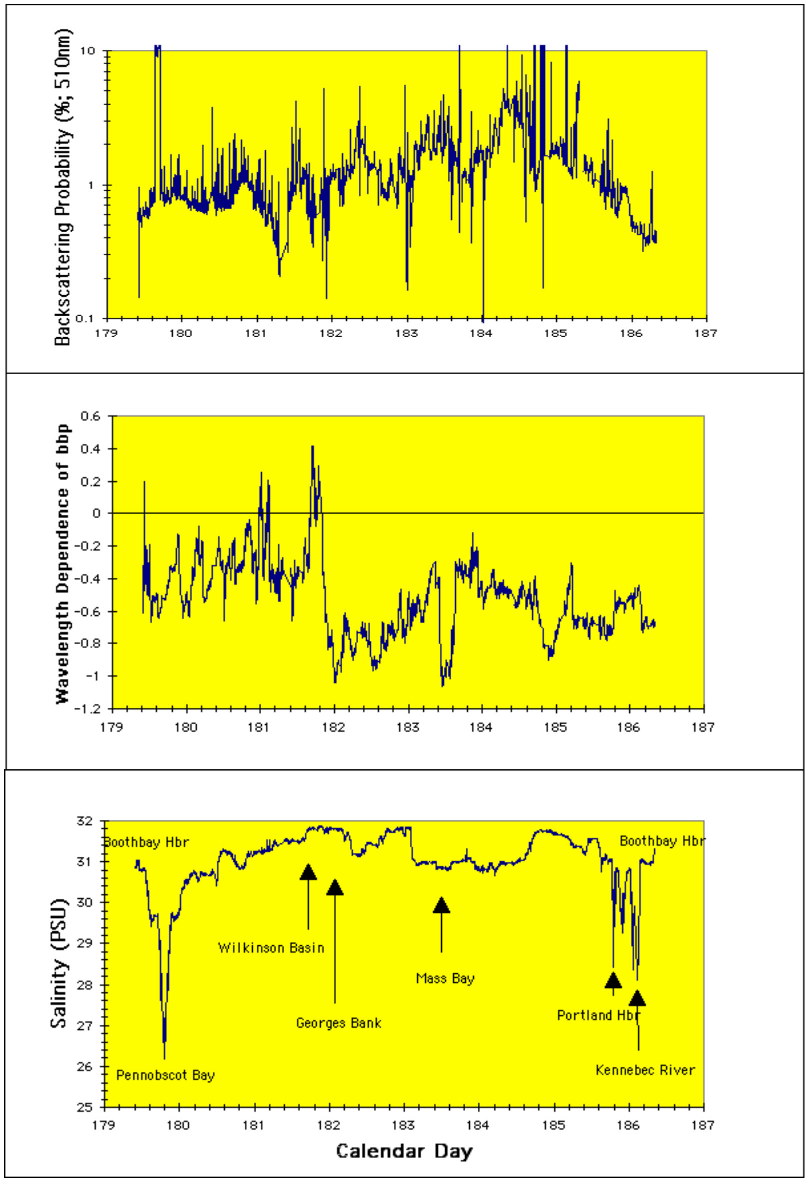

Figure 2- Summary of underway measurements of backscattering probability ($\tilde{b}_b$,top panel), wavelength dependence of particulate backscattering (middle panel), and salinity (bottom panel). Transitions through the various water masses showed large changes in $\tilde{b}_b$ and wavelength dependence.

RELATED PROJECTS

The sorts of data collected during this survey are of interest to the NASA SIMBIOS program.

REFERENCES

Fernández, E., P. Boyd, P. M. Holligan, and D. S. Harbour. 1993. Production of organic and inorganic carbon within a large scale coccolithophore bloom in the north Atlantic Ocean. Mar. Ecol. Prog. Ser. 97: 271-285.

Gordon, H. R., O. B. Brown, R. H. Evans, J. W. Brown, R. C. Smith, K. S. Baker, and D. K. Clark. 1988. A semianalytic radiance model of ocean color. J. Geophys. Res. 93: 10909-10924.

JGOFS. 1996. Protocols for the Joint Global Ocean Flux Study (JGOFS) core measurements. Scientific Committee on Oceanic Research, International Council of Scientific Unions, Intergovernmental Oceanographic Commission: Bergen, Norway.

Utermöhl, H. 1931. Neue Wege in der quantitativen Erfassung des Planktons (mit besonderer Berucksichtigung des Ultraplanktons). Verh. int. Ver. theor. angew. Limnol. 5(2): 567-596.

Utermöhl, H. 1958. Zur Vervollkommnung der quantitaiven Phytoplankton-Methodik. Mitt. int. Ver. theor. angew. Limnol. 9: 1-38.

PUBLICATIONS

Balch, W.M., D.T. Drapeau, B.C. Bowler, A.L. Ashe, and R.D. Vaillancourt. 1999. Backscattering probability and calcite-dependent backscattering in the Gulf of Maine, 1999 Aquatic Sciences Meeting of the American Society of Limnology and Oceanography, Santa Fe, New Mexico. American Society of Limnology and Oceanography. P. 18